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IDENTIFICATION OF ECOLOGO-GEOCHEMICAL ANOMALIES IN BED SILT OF REGIONS WITH SEVERE CLIMATIC CONDITIONS (ON EXAMPLE OF AYKHALSKY MINING COMPLEX)

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Abstract

Ecologo-geochemical estimation of bed slit in Aykhalsky mining complex, located in the permafrost zone, is carried out. The unique natural and anthropogenic geoecological factors of ecological environment formation in cryozone districts are given. Results of investigation of bed slit in Aykhalsky mining complex are presented; sources of pollution and main contaminant elements are marked. Ecologo-geochemical anomalies in bed slit, fixed not only in places of extractive and processing works, but also on the territory of geological exploration activity, are revealed.

Key words: bed slit, ecologo-geochemical anomalies, mining activity, permafrost conditions, environment, heavy metals, anthropogenic factors.

Permafrost regions are territories with unique natural conditions, because formation of geoecological situation consists in complex interaction of abiotic and biotic components. Zone of permanently frozen rocksoccupies more than 60% of the territory of the Russian Federation; it's characterized by extremely active mining activity. However, modern mining production is characterized by intensive usage of natural resources, growth of waste products, and deterioration of environmental quality. These factors put all components of natural environment under the threat.Bed slit also belong to them (Golik *et al.*, 2013; Petin *et al.*, 2014).

Typical example of mining permafrost regions is Aykhalsky mining complex, located on the Vilyuy Plateau in 500 km to the north-west from Mirny city.

The territory of Aykhalsky mining complex belongs to subarctic climatic zone. Climate of the region is acutely continental with a long cold winter (8 months), intermediately hot summer, and short-time transition periods. The

lowest temperaturesare registered in the winter period (-45-65°C), the highest – in summer (up to +35°C). The average annual air temperature is -9 (-11) °C. The thickness of snow cover varies from 30 to 45 cm, in lowering of the relief – up to 1 meter. The area of research is situated in the northeastern part of the Central Siberian Uplandson the territory of the Vilyuy trappean plateau and belongs to the basins of the Morkoka and Alakit Rivers. Present-day relief of the area is determined by its structural-tectonic features, material constitution, and morphology of distributed on its territory magmatic and sedimentary rocks, as well as cryogenic processes.

Valleys of watercourses at the intersection of trappean fields are deeply incutand have the shape of a canyon, they significantly expand in the area of sedimentary layer development, and slopes of valleys become gentler. Relative heightening of interfluves over valley thalwegsis 380-390 m. Flood-plain terraces with the width from 150 to 300 m, in some areas up to 600 m, are linked to bottoms of watercourse valleys.

Rivers of the region are shallow, unnavigable, characterized by changeable regime and mixed feeding, in winter they freeze almost completely. In the period of spring snowmelt (the end of May – the beginning of June) the level of water in rivers and streams may rise up to 1.5-2 m. In average, to the share of spring flow falls 71.5% of the annual flow. The low-flow periodstarts at the end of June – beginning of July; it is interrupted by periodical floods, caused by atmospheric precipitations.

Water of rivers has slight mineralization (under 0.5 gram per liter) and has hydrocarbonate composition.

On the trappean plateau there are thermokarst lakes of isometric and irregularly isometric form with the square from 0.1 km^2 to 4.5 km^2(Lake Ogo-Kyuel). All lakes are shallow, their depth is not more than 1-2.5 m. Lakesides are swampy. Rivers and lakes of the district are sources of fresh water for technical and domestic water supply.

The territory is situated in the area of development of permafrost rocks, their thickness changes from 340 to 450 m. The depth of seasonable thawing varies from 0.5 to 2.5 m and depends on composition of soils, theirmoisture, character of vegetation, and exposition of slopes.

Economically, the district is one of the main centers of diamond mining industry (Glushkova, 2003). The main settlement is Aykhal village with population nearly 17 thousand people. Besides Aykhalsky mining complex and Amakinskaya geological prospecting expedition, the industrial enterprises of diamond mining complex «ALROSA» alsoworks in the village. In Aykhalsky district frost taiga soilsare distributed. They form on permafrost rocks predominantly of loamy granulometric composition in conditions of cold climate. Bright representatives of such soils arecryogenicand alluvial soils that originate in districts of river-beds (Alexandrova, 1987).

Low ordoviciandeposits are the most ancient outcrop deposits. More ancient multiple-aged depositions of sedimentary cover as well as archean formationswere uncovered by hydrogeological, oil and gas exploratory wells (Ivanov *et al.*, 2005).

Crystal rocks of foundation are presented by light gray, pinky graybiotite amphibole and two-peroxenegneisses, quartzite gneisses, migmatites, amphibolites. Diamond deads are presented by kimberlites and kimberlitebreccias. Kimberlitebreccias (alkaline peridotites) are rocks that consist of fragments of deads and capping (limestones, dolomites, basalts, alloyed by basic kimberlite mass that consists of olivine, phlogopite with inclusion of ilmenite, garnets, and magnetite).

Considering the tectonic pattern of Aykhalsky mining complex, it's necessary to point out that the characterized region is situated in the area of connection of the southern slope of Anabarskaya anteclise and the northeastern edge of Tungusskaya syneclise. In the district there are two structural floors that sharply differ in their frameworkand time of formation – crystal foundation and sedimentary cover. The distinctive feature of crystal foundation structure of the district is that the row of narrow linear zones with the width 1-2 km stands out clearly in the common classification system (taxonomy). They are linked with tectonic boundaries of mapped blocks of metamorphic complexes.

In the hydrogeological plan the explored region locates near the Tungussky cryoartesi an basin, in the sedimentary cover of which there is a unite early paleozoic weak water-bearing formation with the thickness up to 2800 m.

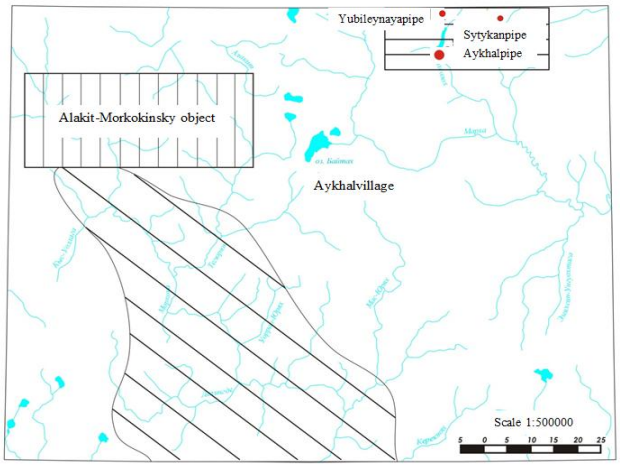
Over the whole territory of the deposit area there are permafrost rocksof cryolite zone with the common thickness up to 720 m. Geomorphology of the territory of Aykhalsky mining complex is quite different from the relief of other northern territories – stepped plateau – in view of the features of tectonic, geological framework of the explored region (Gerasimov, 1976). The studied district is situated on the eastern edge of the Central Siberian Uplands of East SiberianLand of platform uplands, plateau, and plains. In geomorphological relation it's a part of a wide structural denudation stepped plateau, generated in traps, terrigenous rocks of upper paleozoic and terrigenous carbonate rocks of low paleozoic. Modern relief has a definite connection with the ancient structural plan of the region, but during quaternary time its image was considerably changed principally under the influence of neotectonic movements, erosion, and denudation that actively interacted with physical weathering, complex of cryogenic processes and gravitation drift. Structural textural peculiarities and physical features of rocks significantly influenced the intensity of exogenous processes. There are four morphogenetic categories of natural relief on the explored territory: structural denudation relief of plateau, denudation relief of slopes, accumulative relief of river valleys and polygenetic plains,

and frost relief. Anthropogenic relief is presented by motions, mine dumps, formed as a result of diamond mining and reclamation industry (Fig. 1). For the last ten years the anthropogenic influence on relief has highly increased also as a result of intensive development of geological exploration and prospecting works (Petin *et al.*, 2001).

Figure 1. Diamond extractive Aykhalpipe.

Mining activity on the territory of Aykhalsky mining complex is presented by the following kinds of geological works: prospecting, exploratory, extractive, and processing (Fig. 2).

Analyzing the scheme of areas of geological works in Aykhalsky mining complex (Fig. 2), it's possible to draw a conclusion that areas of prospecting works take nearly 40% of the territory. They include: aerial survey, complex of geological-geophysical research, gravity-magnetic, petrophysical, geochemical, and schlich works. South-westwards from Aykhal village there are areas of geological exploration works that take nearly 20% of the studied territory. These areas belong to geological exploration Alakit-Morkokinsky object. It is a perspective diamond containing deposit. Boring and blasting works were executedon this object from 2005 to 2008 for discovery of primary deposits of diamonds. Areas of extractive and processing works occupy nearly 5-7% of Aykhalsky mining complex. They locate closely to diamond containing pipes Aykhal, Sytykan (Sytykanskaya), Yubileynayain the northeastern part of the explored territory.



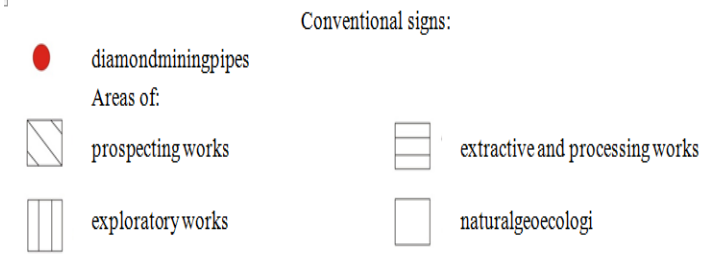


Figure 2. Scheme of exploration of Aykhalsky mining complex territory.

Since 1955 in Aykhalsky region open-pit diamond mining has been produced on three deposits, among them there are pipes «Aykhal», «Sytykan», «Yubileynaya».

Aykhal pipe is achief source of pollution of environment components, particularly of bed slit. Aykhal deposit was opened on the 22nd of January in 1960. Aykhal pipe is situated in northwestern Yakutia, in 450 km to north of Mirny city, in the permafrost area. The deposit is close to the left slope of the Sokhsoolokh-Markhinsky stream valley, it's a pipe of explosion, prolonged in the north-eastern direction (Bobrievich *et al.*, 1959).

In 1960-1961 Aykhal pipe was explored up to the depth 400 m. In recent years the deposit has been prospected up to the depth 900 m.

Mining works at the deposit began in 1961. In accordance with the project, working levelswere uncovered by the external permanent trench, continuation of which is the system of internal trenches with loop form of track that locate along the northern edge of the pit and provide access to the subsurface. Aykhalsky pit is a typical upland pit that locates on the left steep slope of the Sokhsoolokh River valley. In 1981 the opencast mining of diamond reserves from Aykhal pipe was finished: in the loweredsouthwestern part the deposit was wasted, in average, up to the depth 200,0-205,0 m (horizon +295 m), in the heightened northeastern part – up to the depth 260,0-270,0 m (horizon +260 m).

Reconstruction of the pit began in 1989 for mining of explored diamond reserves up to horizon +230 m (the depth in the northwestern part of the pit is nearly 300 m). Kimberlite mining began in 1991 in the process of reconstruction in the pit edges. These kimberlites were processed at the factory № 8.

As far as the pit was reconstructed and kimberlites were extracted, the open- pit bottom reached the design reference mark (+230 m). Whereupon, there was an area of underground kimberlites mining from the northwestern pit edge – in direction of ore body immersion.

For detection of ecologo-geochemical anomalies in bed silt in 2005-2010 geoecological research was carried out (Khovanskaya *et al.*, 2011).

The total area of research, including the area of prospecting, exploratory, extractive, and processing works, makes up nearly 15500 km^2, the southern frontier is located at 100 kilometers' distance from Aykhal village.

Estimation of prospecting, exploratory, extractive, and processing works influence was carried out:

– in the area of impact of extractive and processing works, carried outon diamond pipes Aykhal, Yubileynaya, Sytykan;

– on geological exploration Alakit-Morkokinsky object, located in 40 km in the southwestern direction from Aykhal village and included into bounds of Aykhalsky mining complex.

– on the territory of prospecting works execution, located to the south of Aykhal village (the district of the Morkoka, Delinge, Mas-Yuraykh, Tegyuryuk Rivers).

Bed silt wassampled with the frequency, determined by anthropogenic load density.Samples were taken in the basic watercourses of Aykhalsky mining complex (the Markha, Morkoka, Alakit, Sytykan, Delingde, Tegyuryuk, Kyllakh,Uesya-YuryageRivers, the Sytykan and Sokhsoolokh Streams) with the step of 1 km.

However, in urban agglomerations their density increased up to 0.3 km. Special attention at sampling was paid to such elements of technosphere as downpour and industrial discharge of waste waters, gardening in flood lands, location of pasture lands andmotor transport parking etc. After identifying these circumstances, water samples were taken higher or lower than object of impact. The research was carried out in the low-flow period, becauseit's the most informative period to identify the real state of a water object. The maximum levels of pollution are registered inthe flood period. Samples of bed slit were taken from the depth up to 60 cm. In general, 354 samples were taken (Fig. 3).

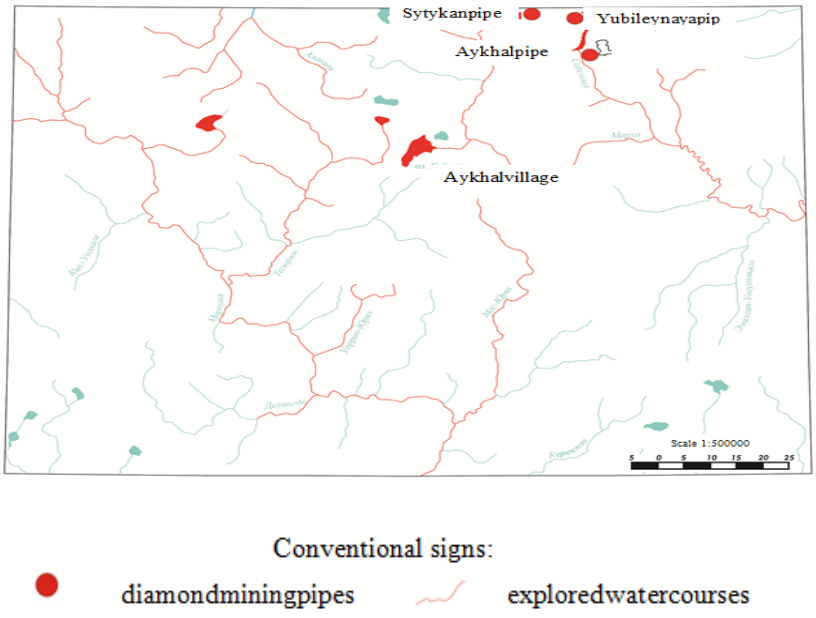


Figure 3. Map of bed slit sampling in Aykhalsky mining complex.

Total pollution index, calculated by formula 1, was used in estimation of bed slit contamination level (Methodical instructions 2_1_7_730-99 – Sanitary assessment of soil quality in settlements (maximum permissible concentrations). Composition of such chemical elements as Sc, V, Cr, Co, Cu, Zn, Sr, Y, Ba, La, and Pb was studied. The level of bed slit contamination is determined by estimation scale, given in the table 1.

Table 1: Estimation of geoecological condition of bed slit.

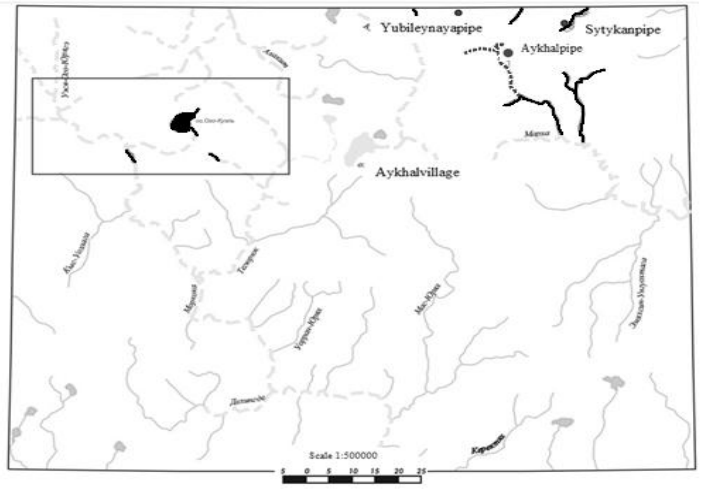
Estimation of geoecological system condition	Bed slit
	Total pollution index
Permissible	<16
Moderately dangerous	16-32
Dangerous	32-128
High dangerous	
Extremely dangerous	>128

Criterion of subtyping is the value of total pollution index (Z_{c_i}), calculated by formula 1:

$$Z_{c_i} = \sum_{i=n}^{n} K_{k_i} - (n-1),$$

where $K_{k_i} = C_i/MPC_i$– coefficients of concentration, normalized in relation tomaximum permissible concentrations (MPC), C_i – content of chemical element in a sample, MPC_i – maximum permissible concentration of a chemical element, n – the number of abnormal chemical elements with concentration ≥1.

The main results received in analysis of bed slit contamination on the territory of Aykhalsky mining complex by the value of total pollution index are presented as a map of their ecological condition (Fig. 4). It's also necessary to note the complex impact of natural and anthropogenic factors on composition of bed slit. Natural factors are conditioned by areas of tectonic disturbances and revealed in content of chromium, cobalt, yttrium, niobium, scandium. Abnormal concentrations of these elements are observed in rivers, drain rocks of crystalline foundation. Such natural anomalies are marked in valleys of the Morkoka River and the Alakit River.



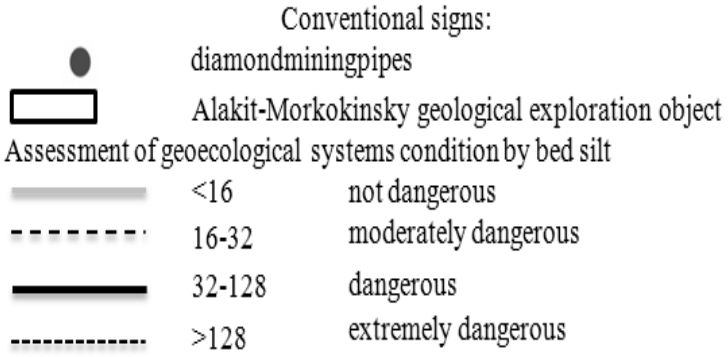


Figure 4. Map of ecologo-geochemical estimation of bed silt by the value of total pollution index in Aykhalsky mining complex.

High lead content is observed on Alakit-Morkokinsky object, in the areas, where geological exploration works are carried out. Lead has principally anthropogenic origin; gas outbursts of internal combustion engines contain tetraethyl lead. Lead generatesat borings in the area of explored object. Bed silt of the Yesya-Yuryage River, wellhead part of the Bludlivy Stream, Lake Ogo-Kyuel, a small part of the Morkoka River valley is characterized by dangerous ecological condition.

In the northeastern part of the studied territory bed silt is characterized by dangerous and extremely dangerous ecological condition, it confirms the intensive impact of extractive and processing works. Peaks of pollution are marked in the areas of diamond-mining pipes Aykhal, Sytykan, and Yubileynaya. The main contaminating elements are Zn, Pb, Cu, Ni, Cr, Co, which penetrate into bottom deposits, when drilling-and-blasting operations are carried out.

Processing works also make impact on the Sokhsoolokhskoewater storage, where sedimentation of enclosing rocks (containing load, zinc, copper, lithium) takes place.

Ecogeochemical anomalies, conditioned by high heavy-metals content, are observed in the places of execution of extractive and processing works, where bed slit is characterized by extremely dangerous ecological condition. Intensive execution of borings with mining of deep rocks, found at the stage of exploratory works, also intensively impacts the formation of chemical composition of bed silt of explored watercourses. In the consequence, their ecological condition is estimated as dangerous.

By the results of bed silt monitoring in the permafrost district on the territory of Aykhalsky mining complex it's been revealed that bed silt is the object of maximum negative influencein the considered cryozone areas (Khovanskaya *et al.*, 2014).

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